# 52. IWK

Internationales Wissenschaftliches Kolloquium

International Scientific Colloquium

**PROCCEDINGS** | **10 - 13 September 2007**

## FACULTY OF
## COMPUTER SCIENCE AND AUTOMATION

# COMPUTER SCIENCE MEETS AUTOMATION

## VOLUME II

**Session 6 - Environmental Systems: Management and Optimisation**

**Session 7 - New Methods and Technologies for Medicine and Biology**

**Session 8 - Embedded System Design and Application**

**Session 9 - Image Processing, Image Analysis and Computer Vision**

**Session 10 - Mobile Communications**

**Session 11 - Education in Computer Science and Automation**

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## Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

| | |
|---|---|
| Professor Peter Scharff | Professor Christoph Ament |
| Rector, TU Ilmenau | Head of Organisation |

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M. Brandner

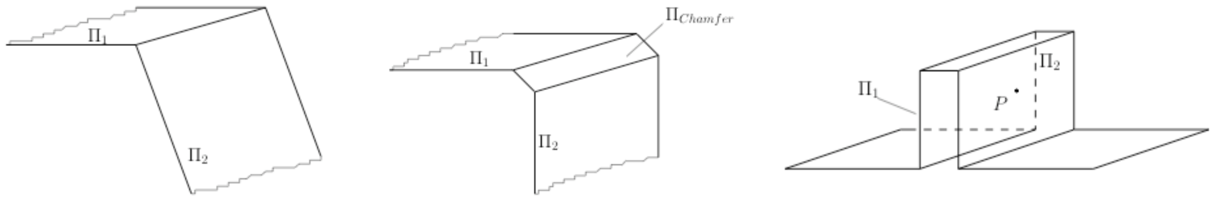
# Vision-Based Surface Inspection of Aeronautic Parts using Active Stereo

## Abstract

Dimensional inspection both during and after the manufacturing process is a valuable tool to identify defective parts and to isolate bad tolerance trends of the production line. Safety critical components as frequently encountered by the aeronautic industry require the inspection of 100% of the production leading to a demand for fast and reliable inspection tools. Vision-based inspection offers appealing properties such as a non-contacting measurement principle and the simultaneous measurement of multiple features on a given part. However, especially in the aeronautic sector the inspection system is often faced with difficult surface properties (e.g. non-coated shiny parts) and a large variety of object sizes ranging from small engine components to large fuselage elements. This work describes an optical sensor prototype based on two active stereo systems used to perform quality control measurements on small-scale aeronautic parts. Experimental results on aeronautic parts show the feasibility of the proposed approach.

## Introduction

The detection of defective parts plays an important role in the production of aeronautic parts. Due to the high complexity and the demanded level of accuracy, inspection systems capable of performing highly accurate quality control measurements are required. Vision-based inspection systems have gained in importance especially for applications that require the inspection of a large number of geometric features within a short timeframe or for automated processing [1]. In contrast to standard mechanical inspection systems such as coordinate measurement systems and measurement arms, optical systems are only restricted by the line of sight.
The robustness of vision-based measurement systems in difficult situations such as changing ambient illumination or presence of highly reflective target surfaces can be improved by using a structured light approach. In this case, the illumination system is used to support the search for corresponding image features in different views of the scene.
Structured light can, however, be used to obtain active stereo setups once both the camera and the light projector are calibrated. Laser sources are frequently used in such applications as resultant projectors have small form-factors and are easy to integrate into the sensor design.
Vision-based inspection of aeronautic parts is confronted with a wide range of object scales. The development presented in this paper targets towards the robust measurement of the geometric entities *wall thickness*, *angle between planes*, and *edge between planes* as outlined in Figure 1. The proposed sensor has been developed as part of a larger project aiming at the improvement and adaptation of image processing tools to aid the quality control and assembly processes in the aeronautic sector.

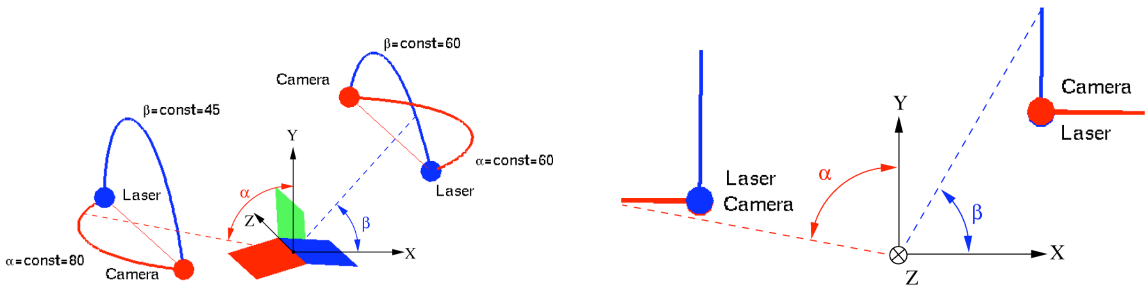


(a) (b) (c)

**Fig. 1:** Target entities to be measured by the proposed sensor. (a) Angle between planes. (b) Edge between planes with chamfer. (c) Wall thickness.

## Active Stereo Setup

A combination of two cameras and two laser projectors is used to capture object properties such as the parameters of planar surface patches, angles between adjacent surfaces, distances, and wall-thickness. The components of the proposed sensor are arranged as outlined in Figure 2. Simulations of different setups showed the maximum performance of the setup in terms of measurement uncertainty for 90° tilt angles between the components. The layout is further optimised so that each combination of an image sensor and a laser projector can act as active stereo pair.



(a) (b)

**Fig. 2:** Geometry of the sensor components. (a) Two cameras (red dots) and two laser sources (blue dots) are placed relative to the sensor coordinate system. (b) Side-view of the setup.

We define an active stereo system as a geometric setup comprising an image sensor and a light source as outlined in Figure 3. Assuming calibrated components the unknown point **X** can be reconstructed in 3D space using the geometry of the projected ray and the observation of the image sensor.

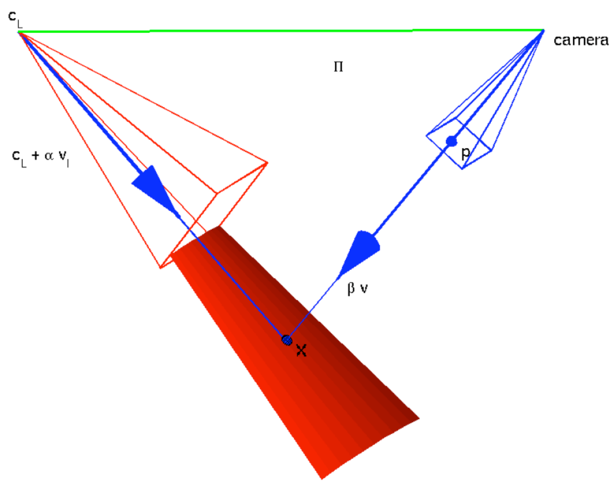



**Fig. 3:** 3D reconstruction using Active Stereo.

The laser projectors used in the sensor are equipped with line-generating lenses such that each laser projects a number of N=10…20 parallel lines. In order to use these lines in the context of the active stereo a geometric model describing the surfaces projected by the laser is needed. Figure 4 depicts the deviation of the projected structures from their ideal straight lines. The different surfaces projected by the laser are modelled using their intersection with a plane orthogonal to the principle axis of the laser in a distance of 1m. These intersections are referred to as profiles and modelled by two polynomials where

$$s_i(t) = \left(p_{i,x}(t), p_{i,y}(t)\right)^T \tag{1}$$

(cf. Figure 4b). Consequently, after substitution of a first and a second order polynomial, the i-th surface projected by the laser is represented by

$$S_i(t) = c_L + \alpha\left(t, a_2 t^2 + a_1, 1\right)^T \tag{2}$$

All measurements performed by the sensor rely on the estimation of planes or piecewise planar structures. As the reconstruction of points in 3D space and consequently the estimate of the plane parameters are straight forward to obtain using the projector model in Equation 2, we subsequently focus on the treatment of parameter uncertainty. The intersection of the i-th surface $S_i$ with a planar surface patch $\Pi_j$ can be reformulated to obtain a quadratic form [2]

$$p^T C_i\left(\Pi_j\right) p = (x, y, 1)^T C_i\left(\Pi_j\right)(x, y, 1) = 0 \tag{3}$$

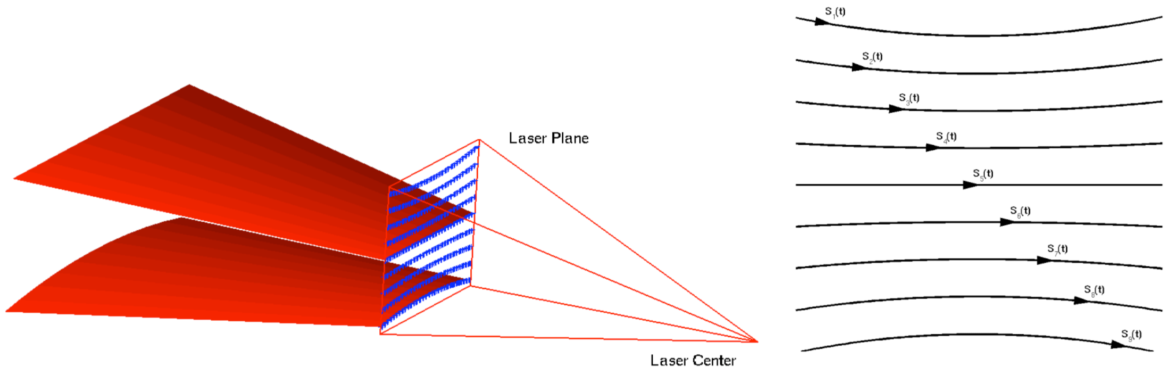
in image coordinates where the parameters of the 3x3 matrix $C_i$ capture the geometry of the setup relative to the planar patch $\Pi_j$. We apply the first order geometric distance measure *d(p,C)* [3] to obtain the Jacobian matrix

$$J\left(C_i, \Pi_j\right) = \left(J_{kl}\left(C_i, \Pi_j\right)\right) = \frac{\partial d\left(p_k, C_i\left(\Pi_j\right)\right)}{\partial \Pi_{j,l}} \tag{4}$$

where k denotes the index of the point on the profile and $\Pi_{j,l}$ is the l-th component of the j-th plane. Assuming additive Gaussian noise deviations of the laser line detector that are small w.r.t. the position of the line intersection, the vector comprising the standard deviations of the plane components is given by

$$\Sigma_\Pi = \sigma_d \sqrt{diag\left(J^T J\right)^{-1}} \tag{5}$$

where $\sigma_d$ denotes the standard deviation of the first order geometric distance *d*.
Based on these results the following section reports on measurements performed with the proposed sensor geometry using an aeronautic part and a robot-mounted sensor.

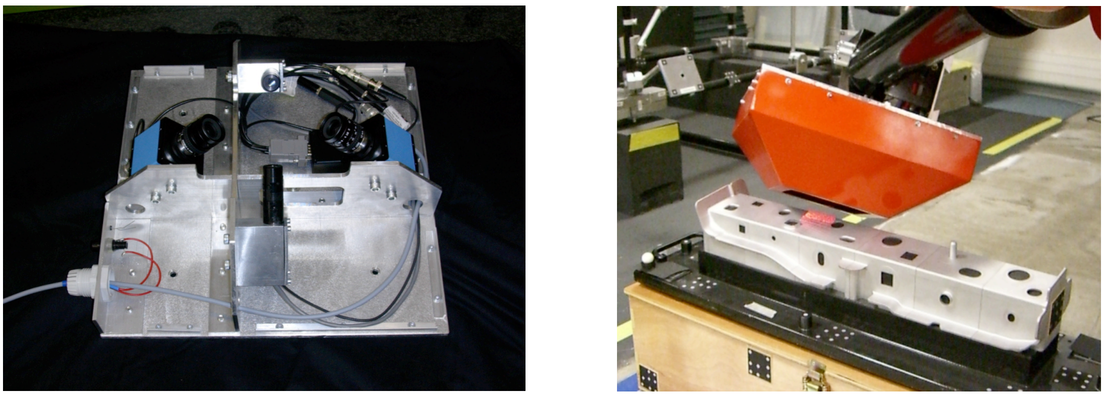



(a) (b)

**Fig. 4:** Geometric modelling of the laser profiles. (a) Surfaces projected by the laser. (b) Polynomial approximation of the laser profiles.

## Experiments

The geometry outlined in the previous section was used to obtain measurement results on an aeronautic part. Figure 5a outlines the optical sensor comprising two 1 MPixel cameras and two laser projectors. This sensor prototype is further equipped with a laser controller. The task of this component is to synchronise the laser illumination (both on/off and illumination power) to the image acquisition. 16 different illumination patterns each consisting of individually selectable laser powers can be stored on the controller and triggered using a remote command. Image acquisition is performed synchronously using the trigger inputs of the cameras. Prior to the measurement acquisition the sensor has been calibrated using a coordinate measurement machine. The calibration procedure includes the estimation of the intrinsic parameters of each camera, the stereo camera pair extrinsics, the parameters of the polynomials of each laser profile, and the laser extrinsics. Planar calibration targets are used to improve the quality of the parameter set of the whole sensor in a final non-linear optimisation step.



(a) (b)

**Fig. 5:** Sensor prototype used for the experiments. (a) Two laser projectors (middle) and two cameras (left and right) are combined. (b) Sensor mounted on the robot arm.

Figure 5b shows the sensor mounted on a robot head. In this experiment the CAD model of the part is known. The position and orientation (i.e. the pose) of the sensor head is related to the robot parameters by means of a hand-eye calibration. Based on the CAD model and the sensor pose the regions of interest (ROI) are determined for both cameras. Measurements performed in this experiment include the thickness of a wall (measurement A), the step between two adjacent planar patches (measurement B), and the angle between to adjacent planes separated by an edge with chamfer (measurement

C). The results of the measurements are summarised in the following table. Note that the expanded uncertainty is computed based on k=3:

| | |
|---|---|
| A - Wall thickness | 3.02+/-0.06 mm |
| B - Normal distance | 0.025+/-0.017 mm |
| C - Angle between planes | 91.29+/-0.18° |

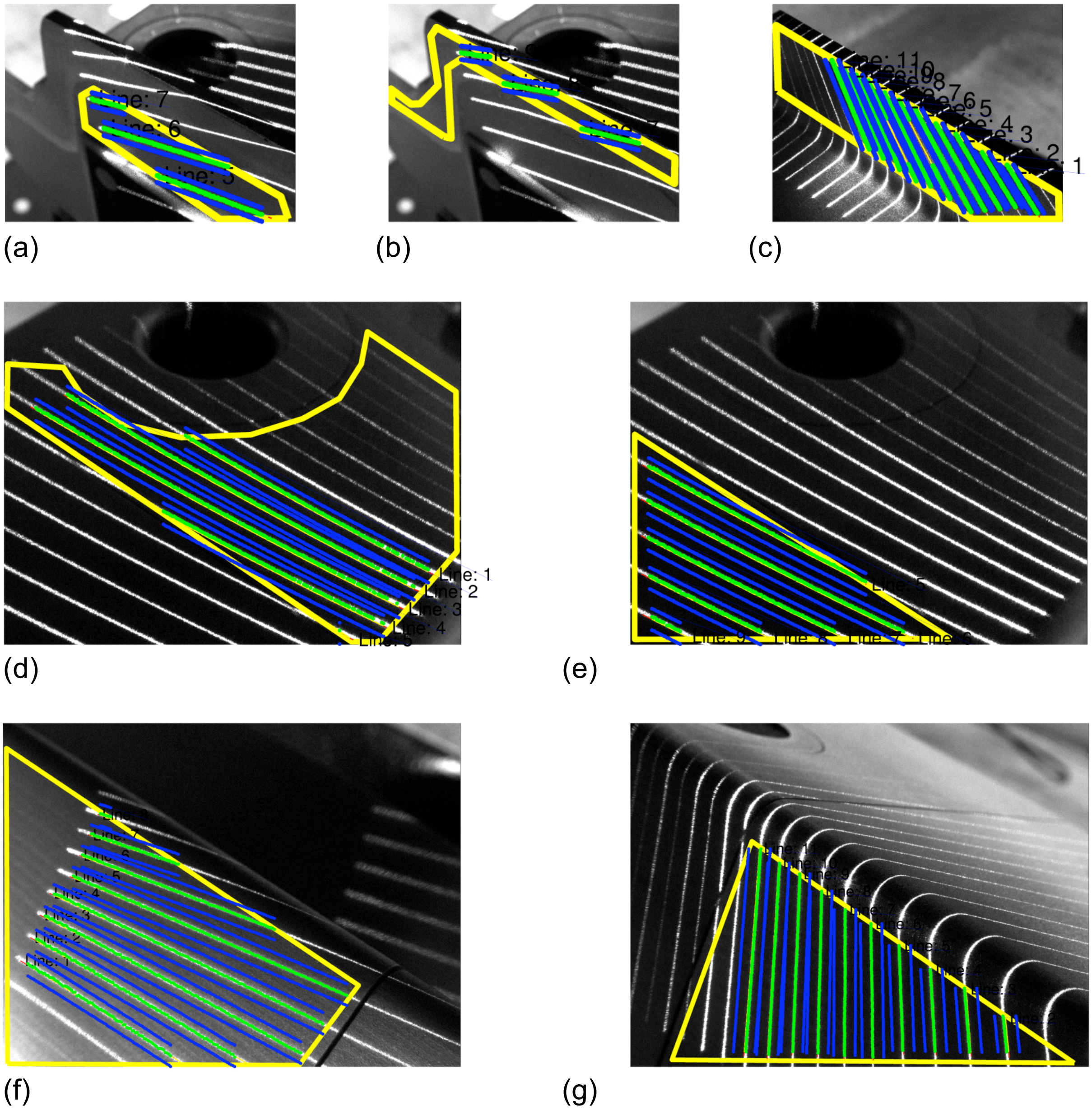



**Fig. 6:** Measurements taken on an aeronautic part. The yellow polygons depict the regions of interest used to restrict the correspondence search in each image. The green profiles are the detected laser profiles. (a-c) Three planar patches acquired during the measurement of wall thickness. (d-e) Measurement of the normal distance between two planes. (f-g) Angle between adjacent planes with chamfer.

## Summary

This paper presents the development of a close-range photogrammetric sensor for vision-based inspection of aeronautic parts. The sensor design is based on two active stereo sets each comprising a camera and a laser projector. The use of the active stereo system allows to robustly estimate plane parameters and derived measurands such as wall thickness of highly reflective surfaces even under partial occlusion. A geometric model for surfaces projected by the laser source is presented which allows for accurate calibration of standard laser projectors and line lenses.
Measurements performed with the calibrated sensor show the applicability of the proposed sensor design to vision-based inspection of aeronautic parts.



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**Author:**
Markus Brandner
Institute of Electrical Measurement and Measurement Signal Processing
Graz University of Technology
Kopernikusgasse 24/IV
A8010 Graz, Austria
Phone: +43 316 873 7773
Fax: +43 316 873 7266
E-mail: brandner@ieee.org